The Evolution of Blade Manufacturing

Brian Glenn
Director, Rotor Blades
Clipper Windpower Technology, Inc.

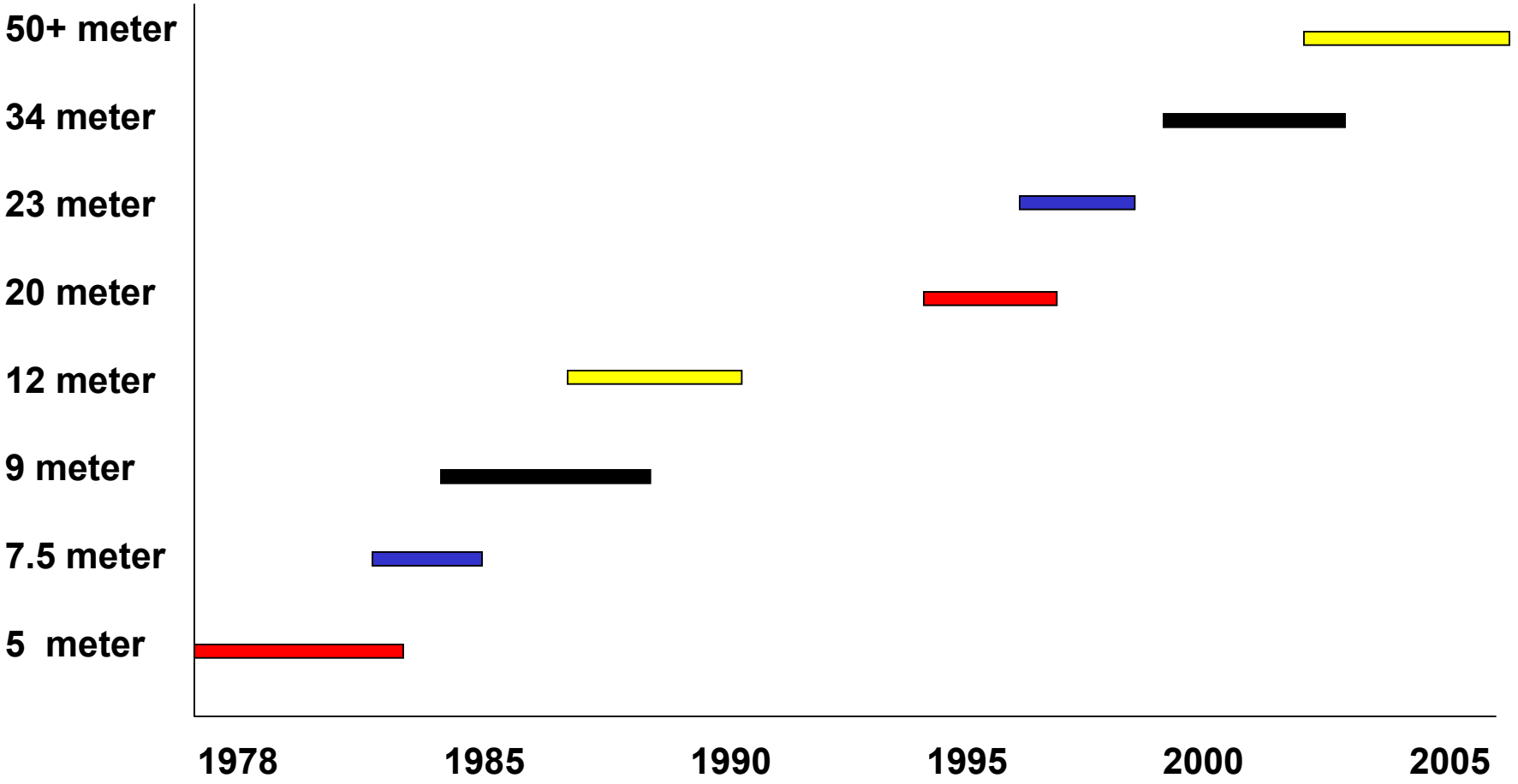
Clipper WINDPOWER

TOPICS

- BLADE SIZE
- THE INDUSTRY
- DESIGN EVOLUTION
  - Materials
  - Processes
- COST
- FUTURE STUDIES

Clipper WINDPOWER

BLADE SIZE OVER TIME



Clipper WINDPOWER

BLADE SIZE OVER TIME – cont'd

- Product life cycle is 3 to 6 years
- New development time is 1 to 2 years
- Tenfold size increase over 25 years (5 meter to 50 meter)
- The industry is maturing (i.e. aviation)
- Original blade length is now the maximum chord length of large blades
- Production methodology must evolve to accommodate large blades

Clipper
WINDPOWER

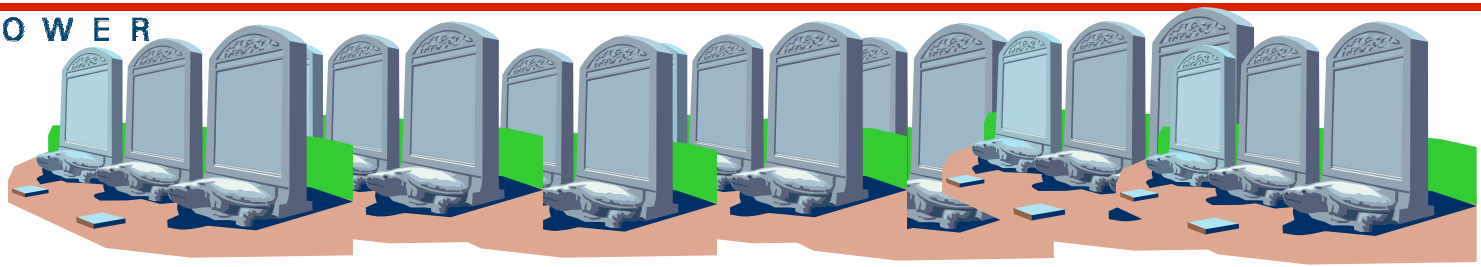
50.5 Meter Blade

MYTH…..

Blade manufacturing is a GREAT business ! !

“Show me the Blade Millionaires”

INDUSTRY - CASUALTIES



Alternegy	Rotorline	Heath Techna
AeroDynamics	Polymarin	EDO Fiberscience
Kenetech	Stork	Flowind
Bouma	Aerpac	Tacke
AeroConstruct	WEG	AWT
Gougeon Brothers	Howden	Carter
Century Design	Storm Master	ATV
Blue Max	Fayette	Wind Master
Polenko	Peterson Products	Wintech

INDUSTRY – cont'd

Companies With Off-the-shelf Product

- LM
- NOI

INDUSTRY - cont'd

Sub-Contract Manufacturers
(Will Build Your Blade)

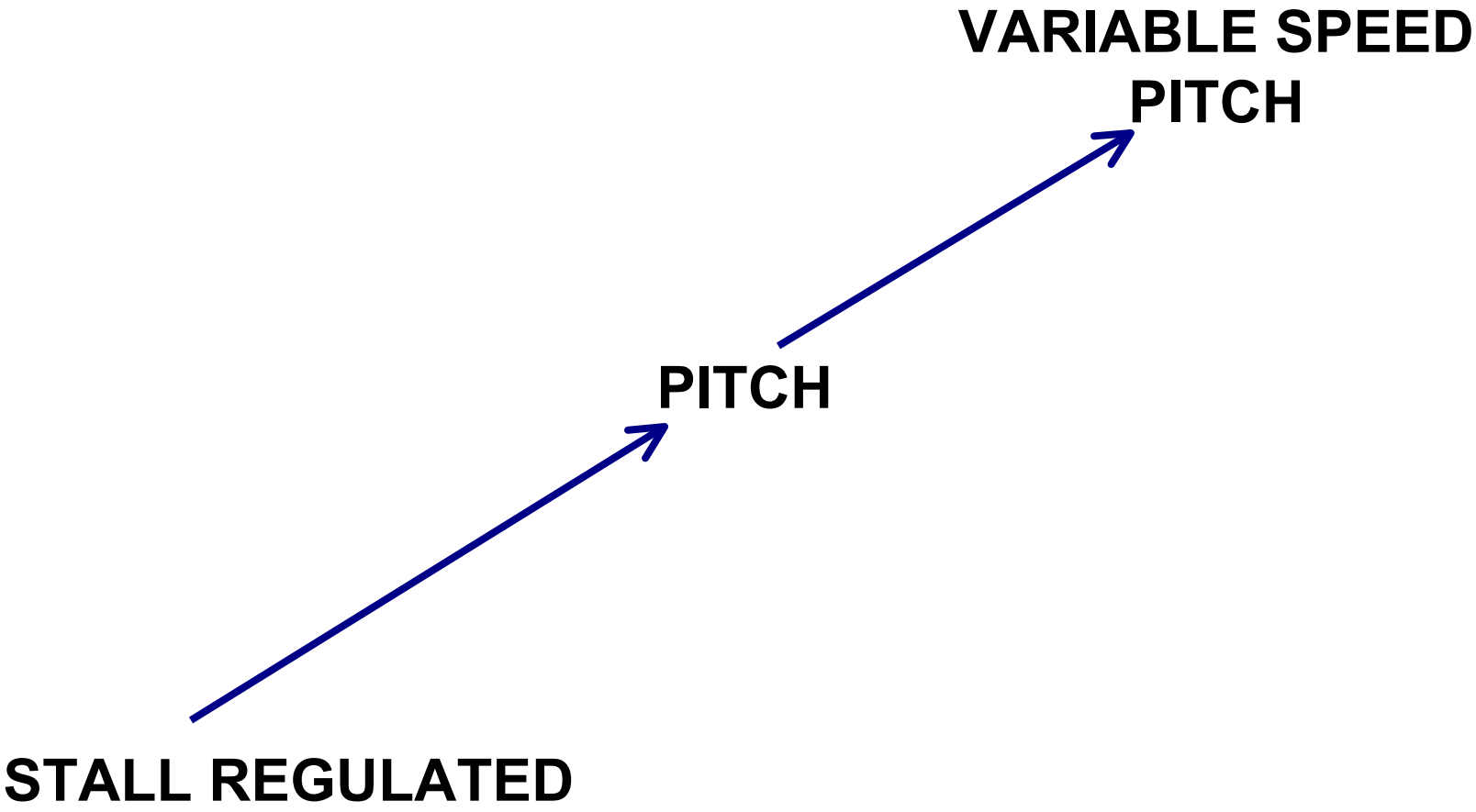
MFG	TPI	TECSIS
A&R	ATV	LM
NOI		

INDUSTRY – cont'd

Wind Turbine Companies
(Manufacturing Their Own Blades)

Bonus	Enercon	GE Wind	Micon
Vestas	Nordex	Gamesa	Suzlon

DESIGN EVOLUTION



DESIGN EVOLUTION – cont'd

- **In the beginning, the turbine was designed around an "off the shelf " blade:**
  - ***90% of blades were out-sourced***
  - ***Built in Western Europe and the U.S.***
- **Today, turbines are specifically designed…driven by loads, site conditions, control strategies, and COE targets:**
  - ***50% of blades are out-sourced***
  - ***Built in Western Europe and U.S….and Brazil, India, & China***
- **In the future:**
  - ***Majority of blades will be designed in-house***
  - ***Built in low-cost countries***

MATERIALS

New Materials ?

• Steel	late 70s
• Aluminum	late 70s
• Wood Epoxy	late 70s
• Polyester E-Glass	late 70s
• Epoxy E-Glass	late 70s
• Epoxy Kevlar	early 80s
• Epoxy S-Glass	early 80s
• Epoxy Carbon	early 80s

MATERIALS – cont'd

Change in Cost over Time: 1984 – 2004 (Approximate)

	Change	Cost
• E-Glass (Roving)	- 15%	$0.60 / lb
• E-Glass (Stitched)	- 20%	$1.00 / lb
• Carbon (Roving)	- 40%	$5.00 / lb
• Polyester Resin	+20%	$0.80 / lb
• Epoxy Resin	- 20%	$1.25 / lb

New Processes ?

• Filament Winding	late 70s
• Wet Lay-up Vacuum Bagged	late 70s
• Wet Lay-up	late 70s
• Pultrusion	late 70s
• Pre-saturated Rovings	late 70s
• RTM	late 80s
• Pre-pregs	late 80s
• Infusion	mid 90s

Clipper WINDPOWER

PROCESSES – cont'd

Filament Winding

Clipper WINDPOWER

PROCESSES – cont'd

Dry Lay-up before infusion

Clipper WINDPOWER

PROCESSES – cont'd

Infusion (in process)

Clipper WINDPOWER

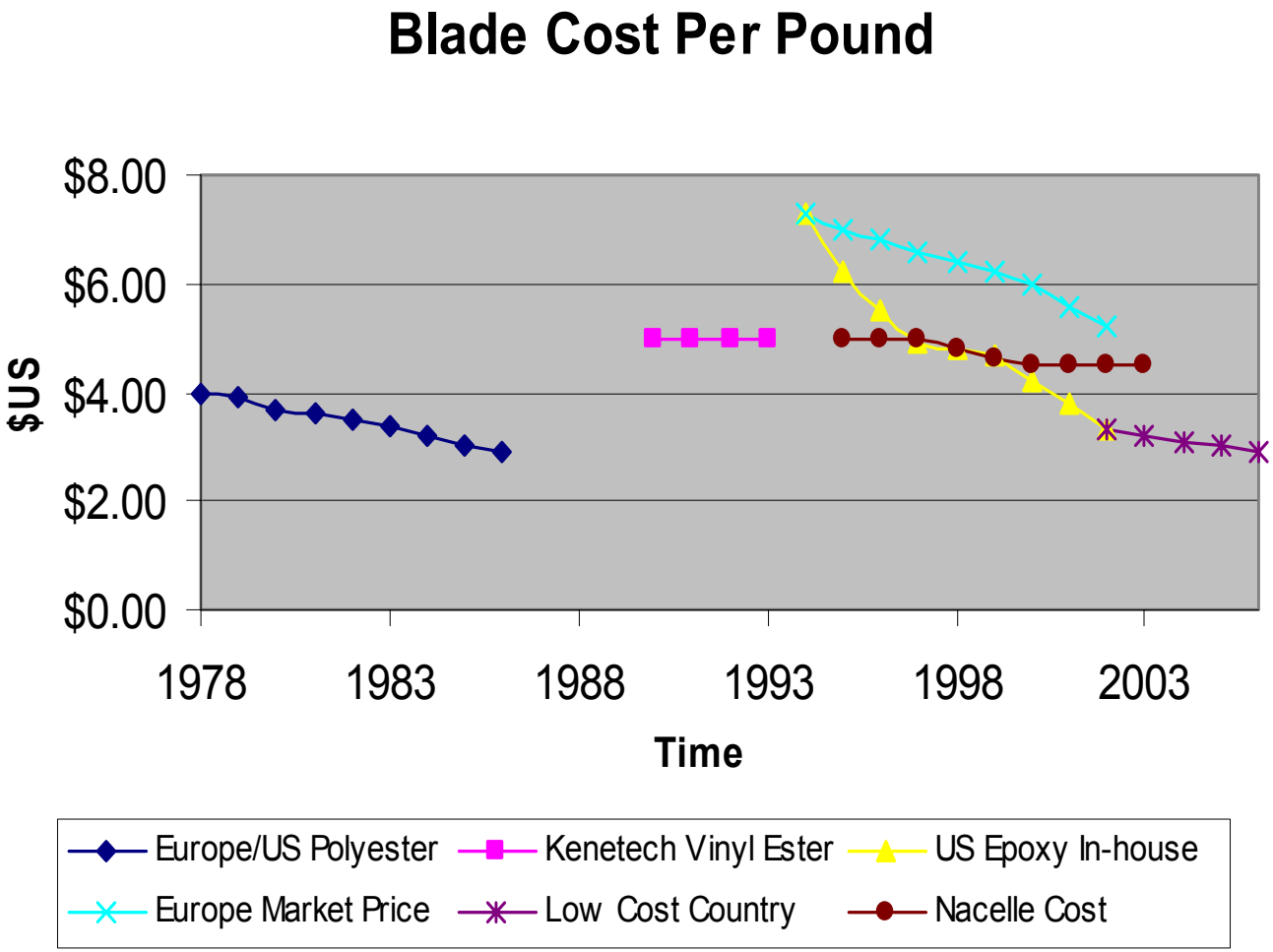
PROCESSES – cont'd

- Industry ramp up ramp down cycles favor automated lower labor hour processes
- Fiber waviness is a major driver
- Changing to Roving vs. Stitched UD saves 2.6% of blade cost; the same as a 20% labor reduction in a LCC
- Fiber sizings – binders need more study to enhance infusion

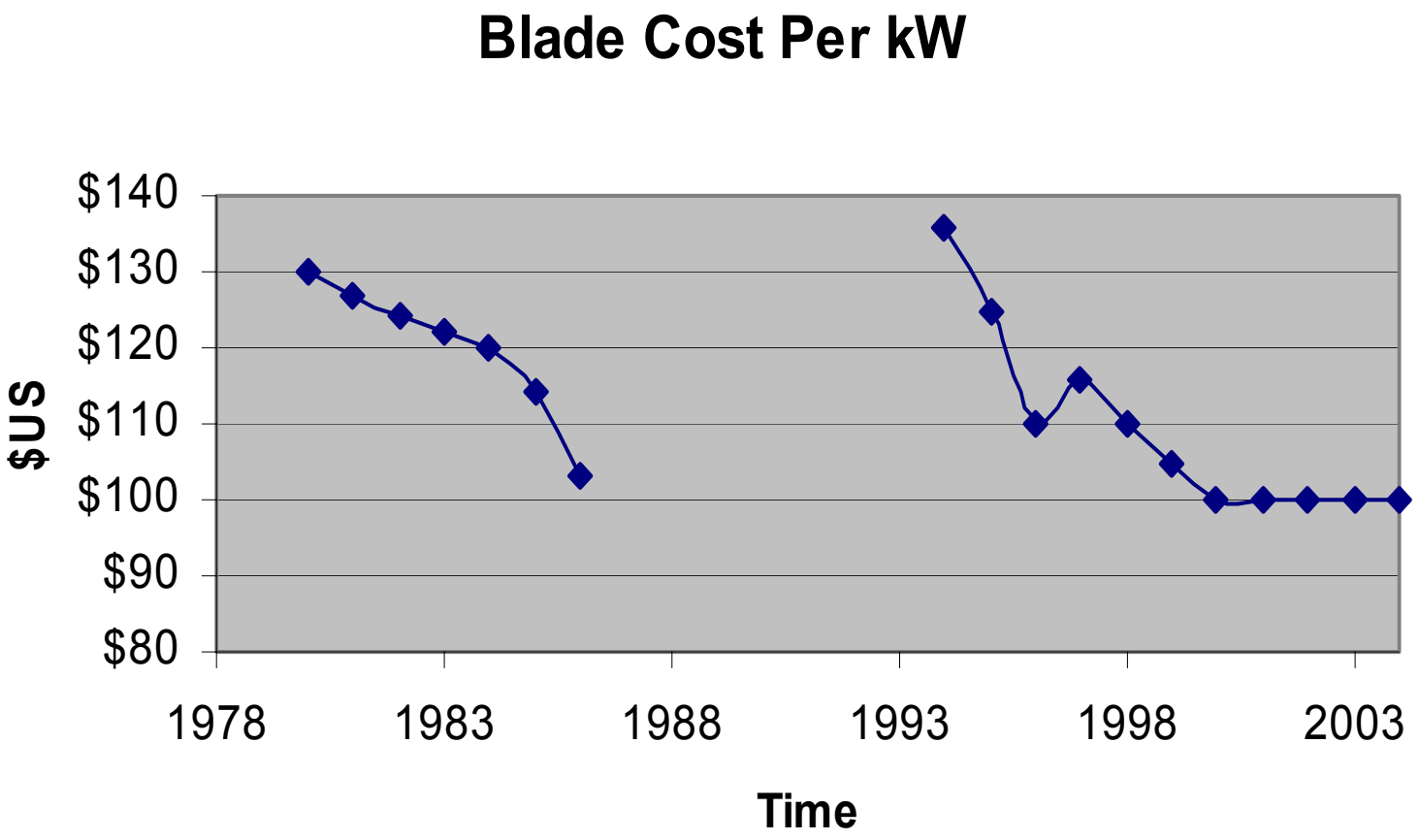
MYTH…..

BLADES ARE EXPENSIVE ! ! !

COST – cont'd

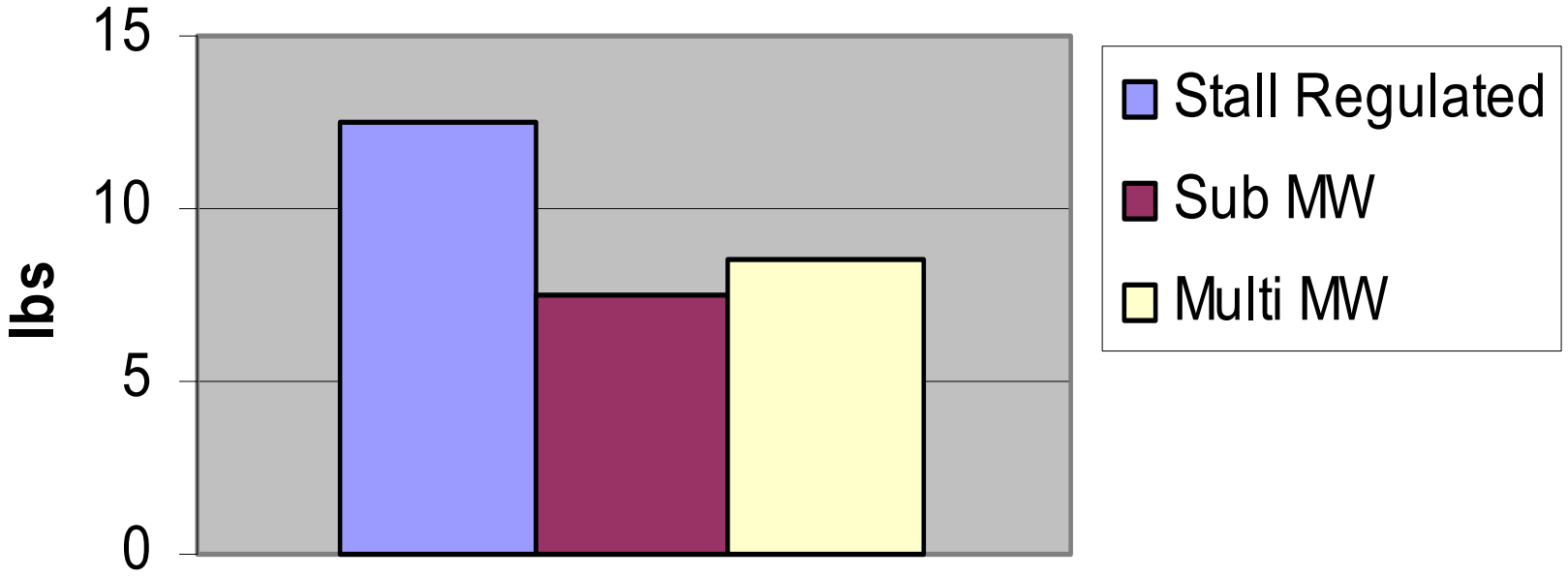

Blade Cost Per Pound
$8.00
$6.00
$4.00
$2.00
$0.00
$US
1978
1983
1988
1993
1998
2003
Time
Europe/US Polyester
Kenetech Vinyl Ester
US Epoxy In-house
Europe Market Price
Low Cost Country
Nacelle Cost

COST – cont'd


Blade Cost Per kW
$140
$130
$120
$110
$100
$90
$80
$US
1978
1983
1988
1993
1998
2003
Time

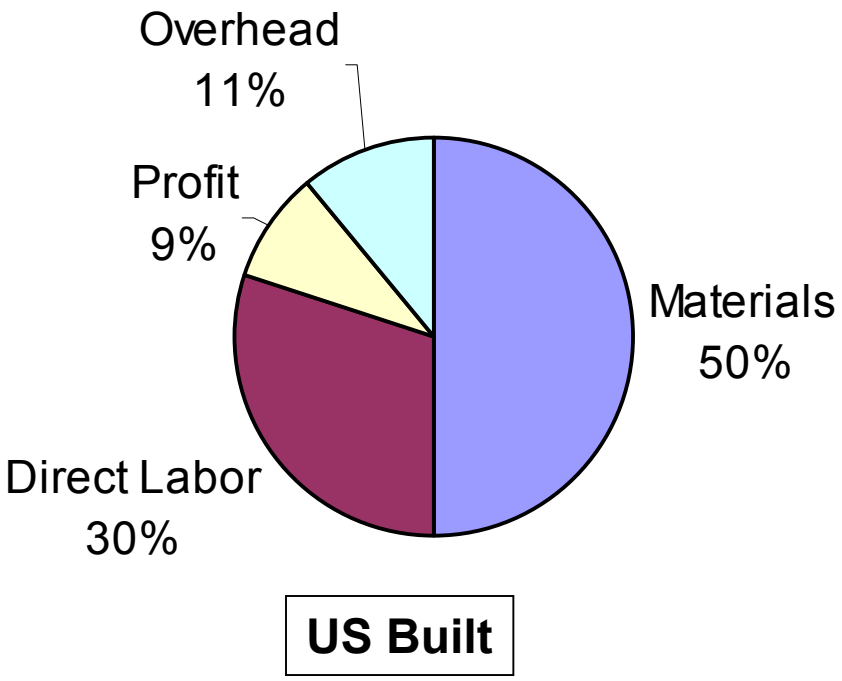
COST – cont'd

BLADE WEIGHT (lbs) Per kW

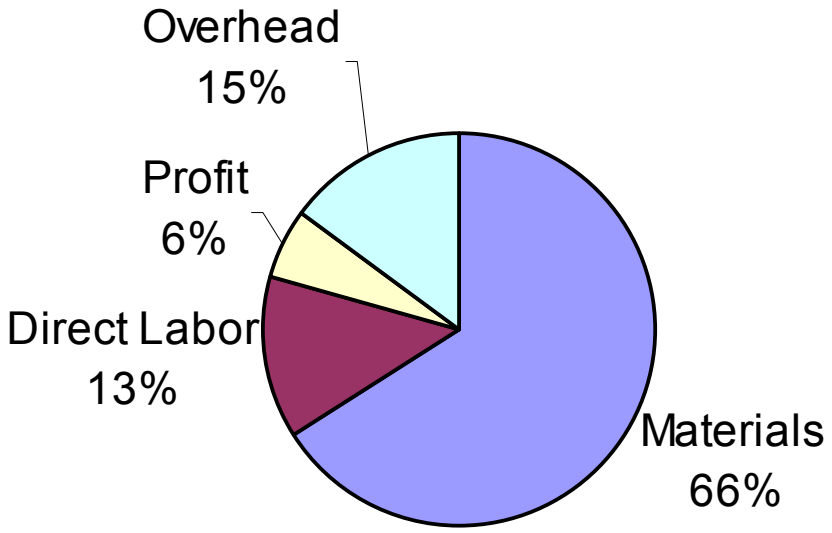


COST – cont'd

Cost Distribution Ex Works



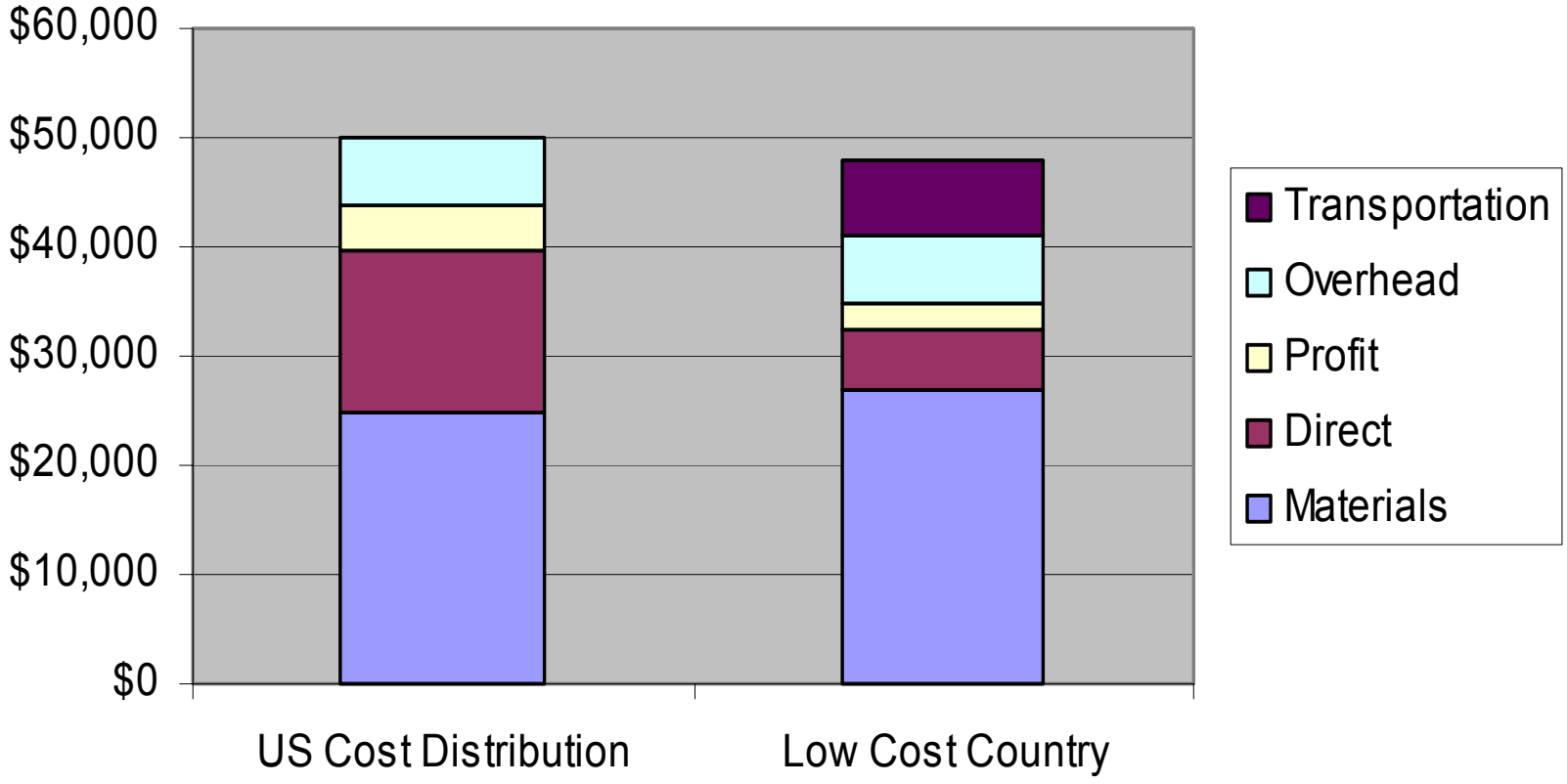
US Built



Low Cost Country (LCC)
18% Less

COST – cont'd

Typical Cost Differences



Clipper WINDPOWER

COST – cont'd

- **Overhead today is about the same in US vs. LCC**
  - ***Opportunity for reduction in LCCs***
- **Labor cost reduction is limited**
  - ***Advantageous to the US / Western Europe Model***
- **Material costs are at a very low level**
  - ***Local supply helps LCC model***
  - ***Risk of increase***
  - ***Change from a stitched product to rovings; achieves large savings***
- **Transportation cost adder is the "wild card"**
- **Best opportunity for cost reduction is a longer uninterrupted product life cycle (steady state)**

FUTURE STUDIES

Aero

- Higher thickness to chord airfoils
- Design for load reduction; interact with loads group, structures, and control strategy

Process

- More consistent automated processes
- Better understanding of volume impact vs. plant size to blade cost.

Load Mitigation

- Feedback loops – control strategy – fiber brag – tower
- Predictive algorithm
- Smart blades – either structure or Aero

Clipper
WINDPOWER

FUTURE